HYDROGEN ENERGY STORAGE FOR GRID & TRANSPORTATION SERVICES

May 14, 2014

Presented by: David Teichroeb
Business Development, Alternative & Emerging Technology

Enbridge Inc.

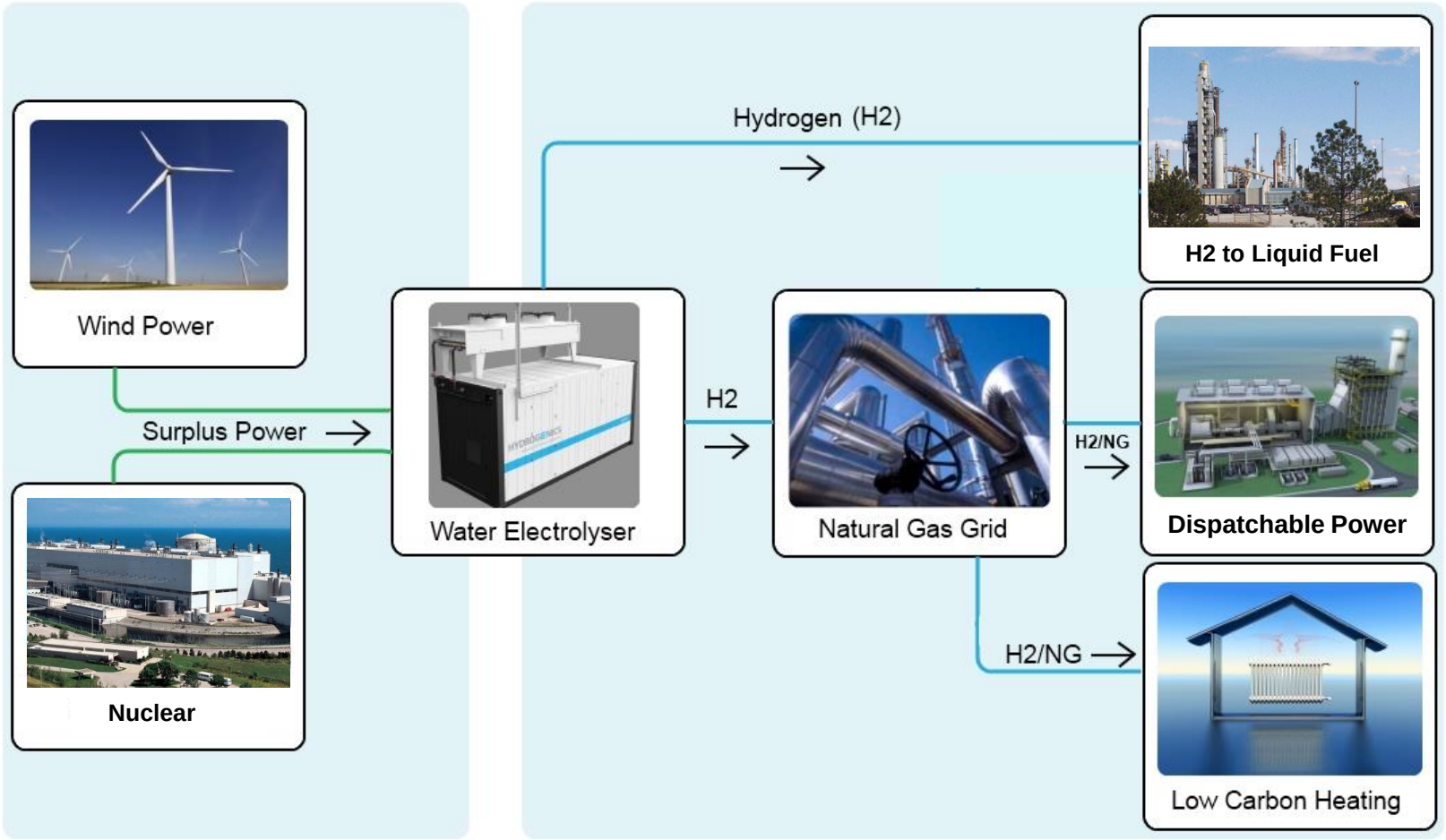
Enbridge Footprint

- Worlds largest liquid pipeline operation
- Canada's largest natural gas distribution company
- Electricity transmission
- Approximately $4 billion in green and alternative energy, including:
  - More than 1800 MW of wind and solar
  - Includes geothermal power, run of river hydro, heat to power
  - Investments in multiple energy storage technologies

Flexibility of Power-to-Gas

Power-to-Gas converts surplus non-emitting power into renewable fuel, power or heat *when and where* it is needed

Power-to-Gas Solution



Smart Energy Grids Interconnect Wires, Pipelines and Refineries for Flexibility

ENBRIDGE

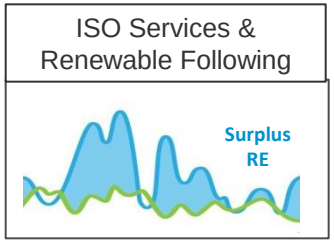
① Conserving Renewables with Less Curtailments

Intermittent Renewables

Power Grids

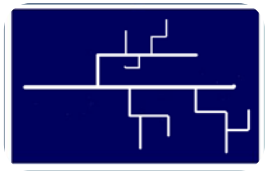
② Exchanging energy currency

PEM Electrolysis



Hydrogen SMR (Refining)

③ Enable Flexible Energy Banking with Storage

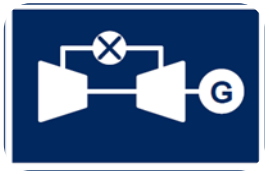


Natural Gas Network

Cavern Storage

Energy Banking

④ Seasonal, Dispatchable, Renewable Power



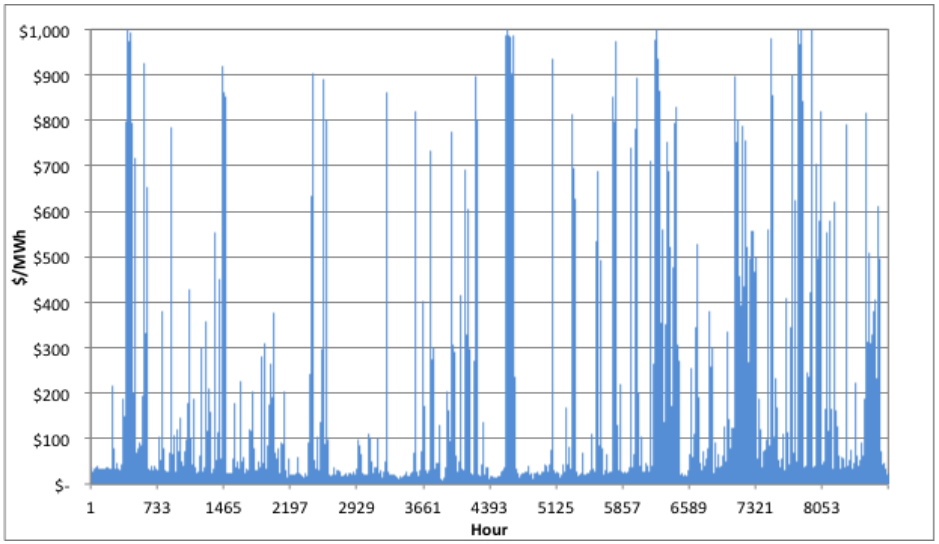
Gas Plants on Renewable Fuel

As Renewable Penetration Grows – Scale Matters

For Bulk Energy Storage, Round-Trip Efficiency Only Matters After Energy is Captured

- Gas storage exceeds potential of alternative bulk storage options
- Consumer Benefit – low marginal cost of pipeline storage
- Power-to-Gas offers more than a thimbleful of storage; > 1330 TWh across North America

Alberta's Market Highlights Need for Bulk, Long-Duration Energy Storage



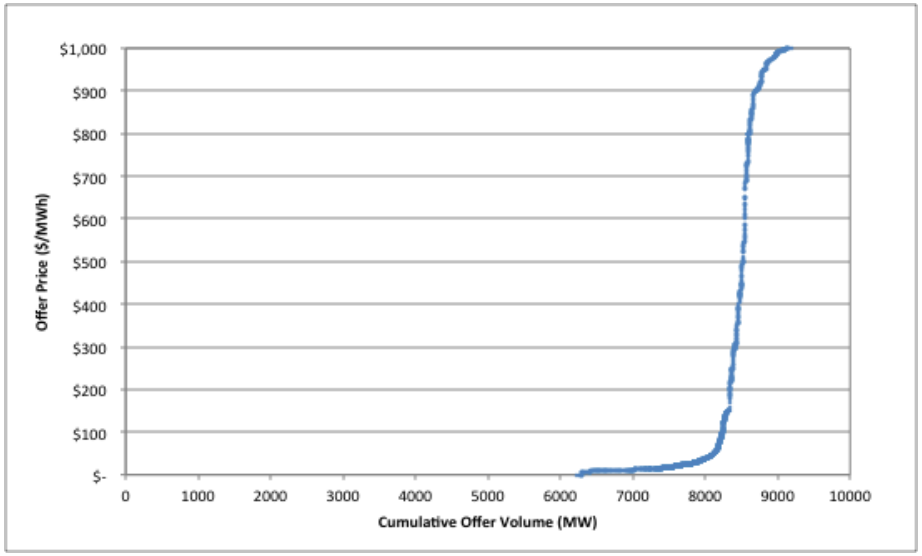
Alberta Distribution of Hourly Prices - 2012

Challenge – how to grow wind

- Significant low-priced power periods mixed with times of high volatility
- Power is only 14% of energy end-use
- Higher wind penetration depresses pool price / wind economics

Power-to-Gas a Possible Solution

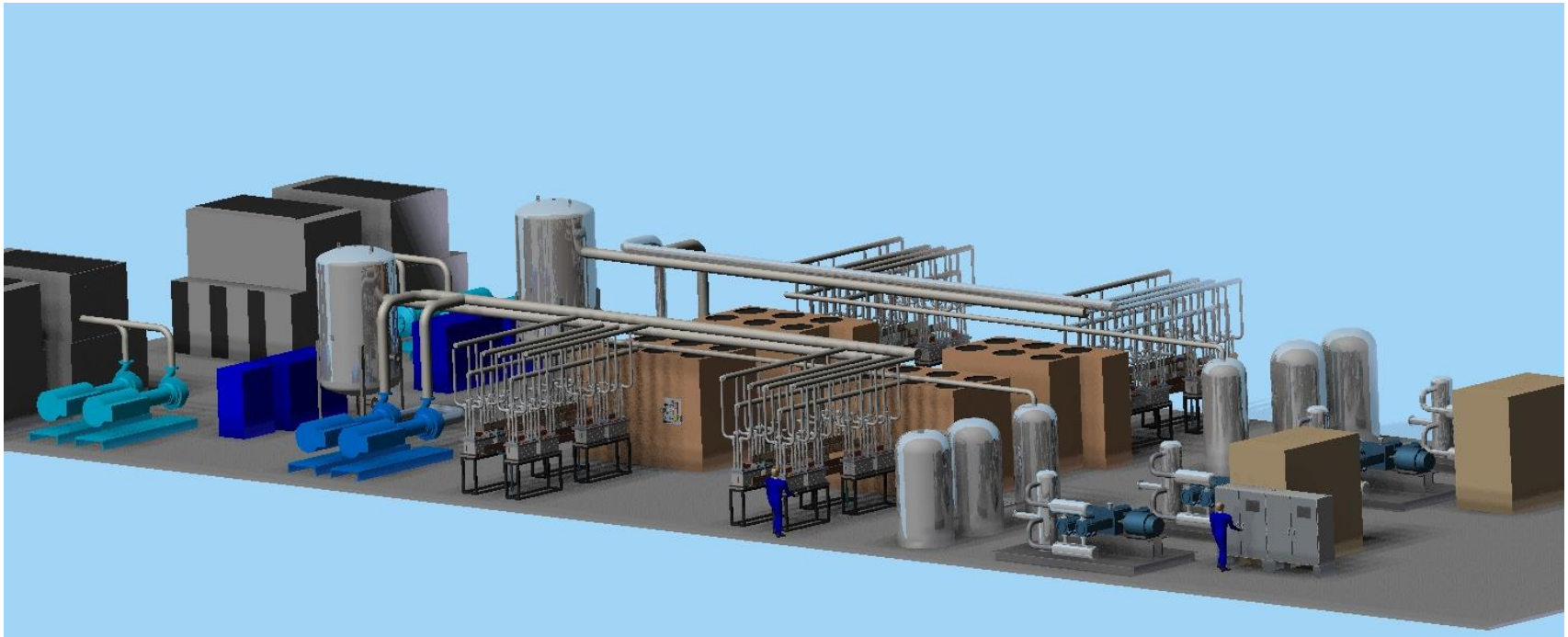
- Natural Gas and Hydrogen end-use significantly larger than electricity
- ISO signals electrolyser to stabilize power grid and pipelines act at a renewable relief valve
- Equivalent of adding new export inter-tie capacity in Alberta system
- ***Never bring energy back to Power***



Typical Alberta Supply Merit Order Curve

Power-to-Gas at Utility / Refining Scale

Technology is a price responsive load, offers fast-acting (Regulation) services to ISO, and simultaneous bulk, long-duration energy storage or, renewable integration into new energy markets



Compact 60 m x 25 m footprint for 40 MW Power-to-Gas Plant

Image Source: Hydrogenics

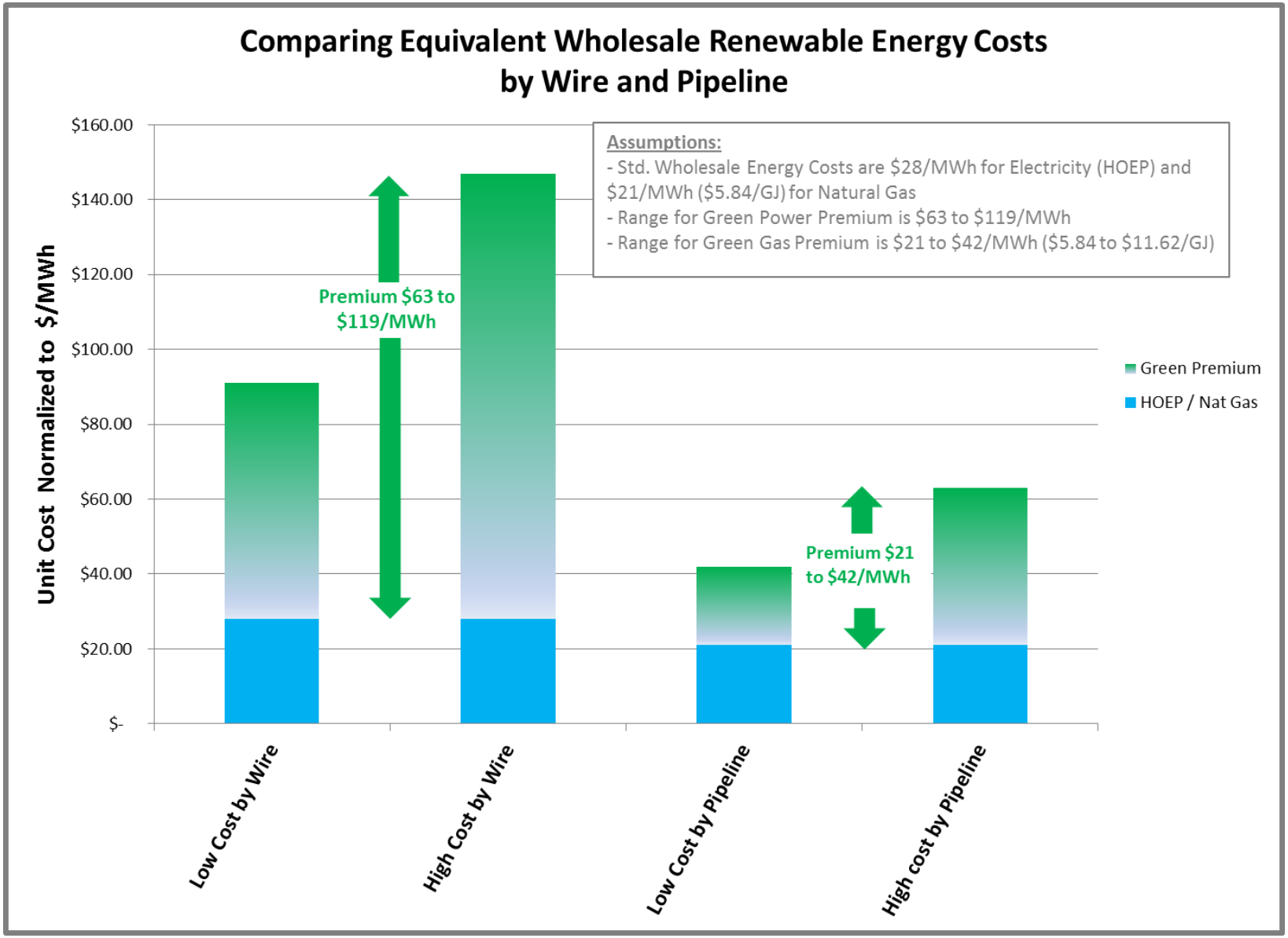
Base Load, Low-Carbon Hydrogen via Electricity and Natural Gas Integration

- **Atlantic Hydrogen Carbon Saver Technology**
  - 1500 kg / day hydrogen production facility in St. John, New Brunswick

Electricity and natural gas combined to produce two high-value products:

- **Hydrogen for oil refining, transportation fuel, HENG, etc.**
- **Industrial Carbon for steel production, rubber goods, etc.**

Comparing Renewables Delivered by Wire & Pipeline (Ontario, Canada Data)



Current Development Activity

- Enbridge and Hydrogenics developing Ontario pilot
  - 2 MW design rating; 25% overdrive capability
  - Ontario RFP for Energy Storage (Regulation) one possible contract path – others are emerging
  - Objective: Validate 80% + system efficiency for energy delivered into natural gas pipeline network
    - If average power supply mix has less GHG's than CCGT; supply energy to consumers as green gas
- Targeting construction 2014-2015 with renewable hydrogen injection into natural gas pipeline system
- Screening for Alberta host site; 5 -10 MW Power-to-Gas project; U.S. developments also underway
- Future scale; 5 to 50 MW distributed systems
- Advocating for market rules that support storage investments in North American markets
- Building support for pan-North American gas quality and hydrogen interchangeability standards for NG pipelines

Hydrogenics Electrolyzer

Underground Gas Storage

Supportive Policy & Market Rules Required to Smooth Adoption of Power-to-Gas

1. Energy policies, RECs and RPS objectives should consider least-cost solutions for more efficient use of existing infrastructure / energy corridors (wires and pipes)

2. Energy storage, including Power-to-Gas, must be a wholesale transaction for input energy purchases (i.e. cannot buy retail - sell wholesale)

3. Consider how Power-to-Gas – linked with renewables – could provide alternatives for refiners to meet low-carbon fuel standards (i.e. renewable hydrogen as an alternative to biofuel/ethanol mandates)

4. Consider carbon abatement efficiency vs. round trip electricity efficiencies
   - As the power grid carbon intensities reduces, it will be increasingly important to ensure energy storage is achieving actual emission reductions
   - Round-trip evaluations need to consider wholesale energy into storage and its subsequent delivery to consumers, regardless of end-use (i.e. renewables by pipe)

5. Renewable hydrogen for refining can be supportive of wind growth

6. Scale of gas storage can offer a price responsive, alternative market for wind developers if green gas is part of RPS mandates (e.g. California's AB32)

7. Energy regulators and policy makers should identify ways to encourage the pipeline industry's adoption of gas quality standards for initial levels of hydrogen blending

Q&A

david.teichroeb@enbridge.com
647-393-1894 (cell)

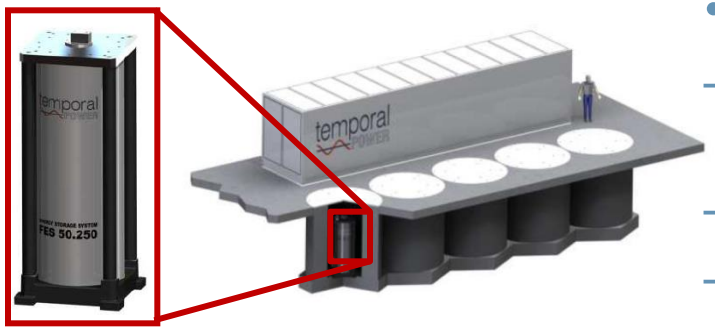
Backup Slides

Investing in Multiple Storage Technologies

Source: Hydrogenics 2MW Power-to-Gas Project in Germany

Hydrogenics, Mississauga, Ont.

- **Electricity Storage with Hydrogen**
  - Power-to-Gas uses hydrogen electrolyzers for bulk storage of surplus renewable power
  - Store renewable hydrogen in natural gas grid
  - Grid stabilization and integration of renewables



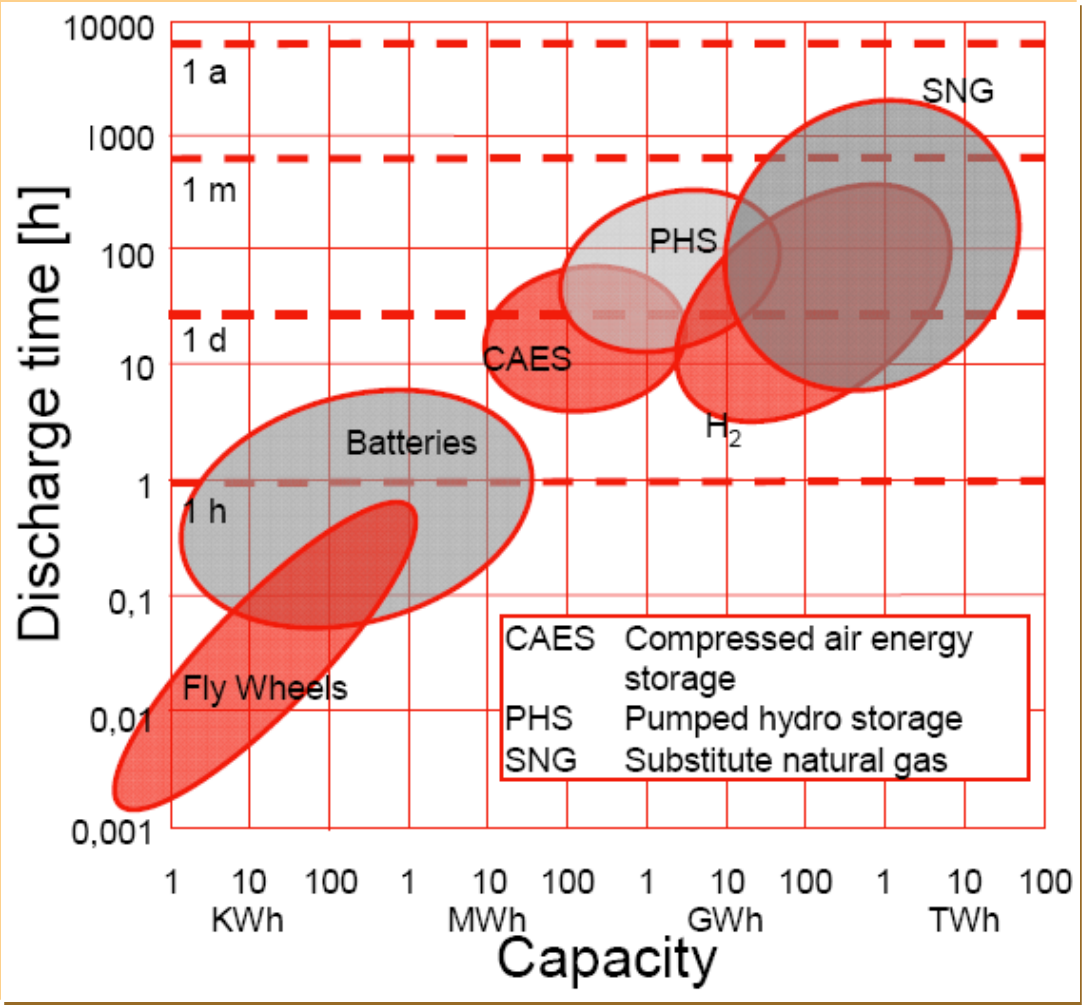
Source: Temporal Power

Temporal Power, Mississauga, Ont.

- **Flywheel Energy Storage**
  - Flywheels enable correction of short-duration power imbalances
  - Mechanical battery storing kinetic energy
  - Renewable integration and system regulation

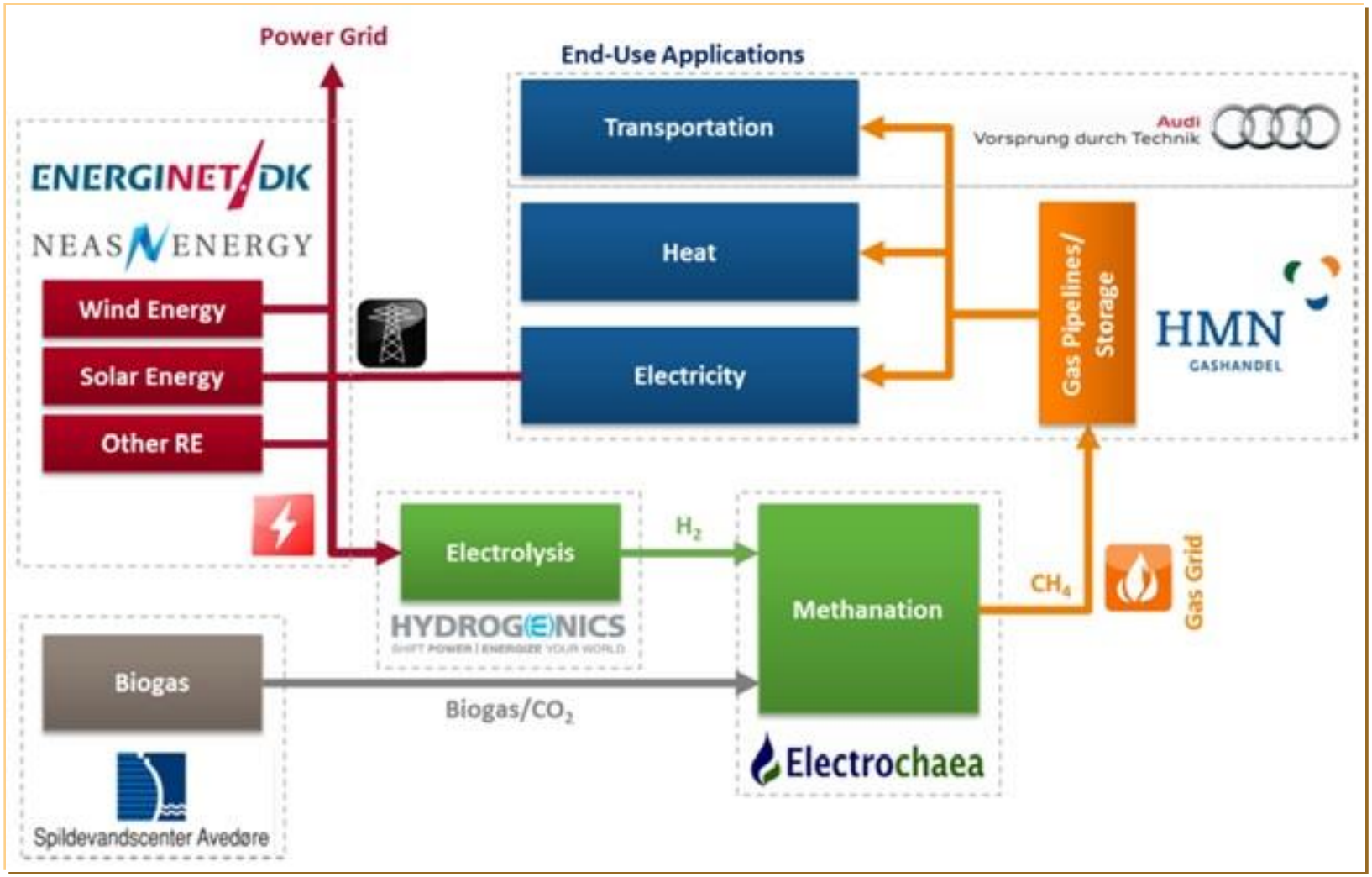
Different Needs Require Different Solutions

- No single storage solution will meet all requirements
- Long-duration storage with hydrogen opens new opportunities



Source: International Gas Union Research Conference 2011, Abstract from Dr. Gerald Linked

The Future Power-to-Gas Story



Source: Hydrogenics and Project Collaborators; ("BioCat") Project in Denmark

Benefits to Electricity & Natural Gas Sectors

ISO
Renewable Integration

Gas Utilities
Green Gas

Purchasing Energy Services

Power-to-Gas Operators

Power Services

Pipeline Services

1) Balance power grid for less $$

2) Reduce curtailment of wind, hydro & nuclear

3) Enable renewable conservation

1) Green gas from wasted or low-value energy

2) Gas storage exists, is proven & low cost

3) Renewable premium on customer bill is less

Real Operational & Consumer Benefits, but Contracting Silos Exist in Most Market Rules

Flexible Energy Infrastructure by Integrating Pipelines & Wires

ENBRIDGE

Significant Energy Storage Exists Today

- Canada already has over 800 billion cubic feet (0.8 Tcf) of underground gas storage
  - Canada's natural gas system stores equivalent of 234 TWh
    - This is over 40% of annual electricity use
- United States has approximately 4 Tcf of underground gas storage
  - Gas cavern storage stores equivalent of 1100 TWh
    - ~ 30% of the total 2011 U.S. electricity consumption
- At 5% hydrogen by volume blending, the existing North American natural gas storage can offer > 66 TWh of storage – the only incremental costs is the electrolyser

An Alberta Example - GHG Reductions

Modeling of GHG Reductions Based on Power-to-Gas Output Supplying Different End-Use Markets

Scenarios	GHG Reductions 2013-2022 (10 years)	GHG Reductions 2013-2032 (20 years)	GHG Reductions 2013-2050 (37 years)
	kilotonnes	kilotonnes	kilotonnes
1. Hydrogen Production for Upgrading	1,070	2,888	7,680
2. Natural Gas Offset (regardless of end-use)	830	2,238	5,952
3. Electricity Generation Offset	971	2,620	6,968

- **Assumptions:**
  - **Market penetration based on AESO's current projected wind capacity in Alberta.**
  - **Wind capacity factor of 32% which is based on actual performance from 2008-2012**
  - **Electrolyzers store (charges) for 63% of the time**
    - **based on the availability of wind power at $40/MWh or less (between 2009-2011)**
    - **Assumes electrolysers capacity is 5% of markets installed wind capacity**